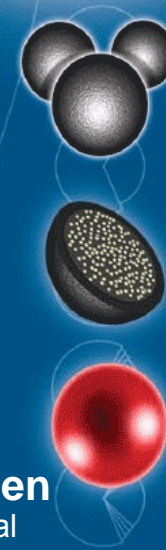
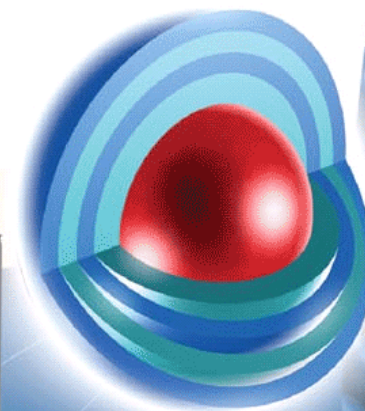
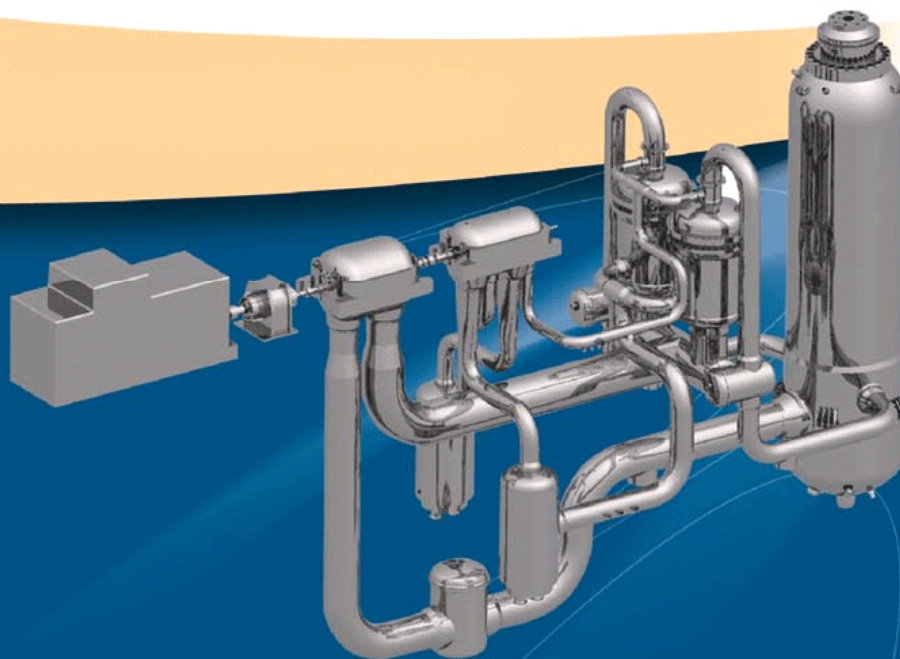


Beyond Electricity – Nuclear Process Heat

32nd Annual WNA Symposium - 2007



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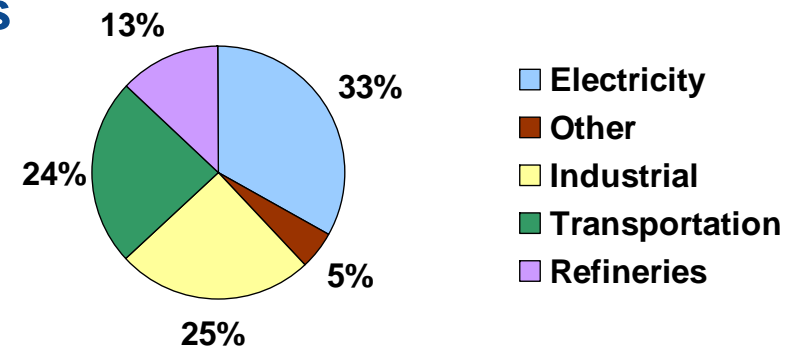


Beyond Electricity



- **Nuclear power plants today supply ~16% of global electricity**
- **Process heat can expand nuclear applications to other energy sectors**
 - Industrial, Transport, Refineries
- **Process Heat Opportunity**
 - Stable process energy costs
 - Displace natural gas and other premium fuels
 - Reduce CO₂ emissions

World CO₂ Emissions by Sector



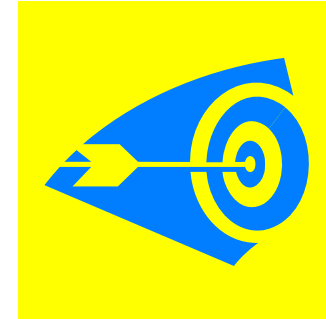


Why PBMR for Process Heat?



- **Right heat delivery temperatures (up to 900°C)**

- Catalyst reactions (reforming, water splitting)
- High pressure steam (oil sands and heavy oil recovery)
- Can be extended beyond 900°C once IHX technologies available



- **Right size and outputs (400-500MWt)**

- Matches industrial plant sizes
- Matches incremental process heat demands
- Modularity enables scalability



- **Timely market entry**

- Builds on South African Demonstration Power Plant (DPP) Project

- **Enhanced Safety Features**

- Small nuclear footprint
- Allows proximity to customer facilities
- Easier acceptance by process industry



- **Clean (no CO₂)**

Markets & Applications



PROCESS TEMPERATURE	Up to 700°C	Up to 900°C
ELECTRICITY APPLICATIONS	<ul style="list-style-type: none"> Rankine Cycle 	<ul style="list-style-type: none"> Brayton Cycle with desalination option or Rankine Cycle Cogeneration
PROCESS APPLICATIONS	<ul style="list-style-type: none"> Steam 	<ul style="list-style-type: none"> H₂ or Syngas (via Steam Methane Reforming) H₂ and O₂ (via Thermo-chemical water splitting)
PROCESS MARKETS	<ul style="list-style-type: none"> Cogeneration and desalination Oil Sands & Heavy Oil Recovery Refinery & Petrochemical Facilities Ethanol production 	<ul style="list-style-type: none"> Merchant hydrogen (i.e. hydrogen-powered vehicles) Syngas for ammonia and methanol production H₂ and O₂ for coal-to-liquid & coal-to-methane processes H₂ for refinery and petrochemical processes H₂ for steel production O₂ for oxyfiring of fossil fuels with CO₂ capture

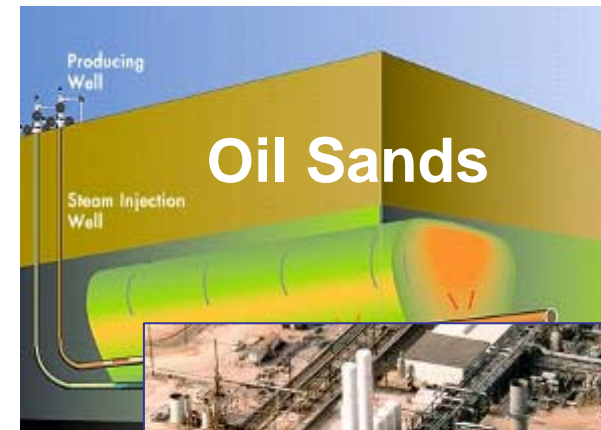


- **Entry Markets: Process Steam**

- Oil Sands and Heavy Oil Recovery
- Refinery / Petrochemical Process Steam and Cogeneration
- Desalination

- **Follow-on Markets: Hydrogen**

- via Steam Methane Reforming (Bulk Hydrogen, Ammonia, Methanol)
- via Water-Splitting (H_2 & O_2)
 - Bulk Hydrogen
 - Coal-to-liquids
 - Coal-to-methane



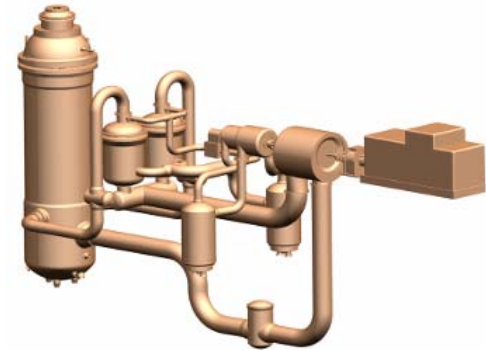


PBMR Projects Update



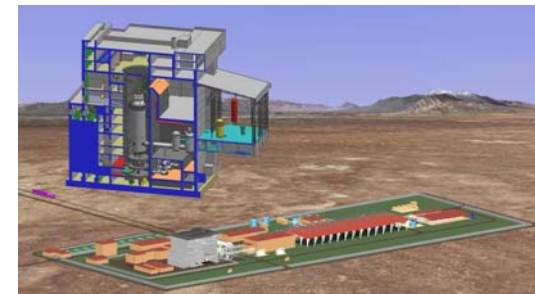
- **First of Fleet Power Plant (DPP) - ROT up to 900°C**

- Basic design completed; detailed design underway
- International supply team in place
- Extensive test programs underway
- Construction scheduled 2009; criticality 2013



- **Process Heat Plant (PHP) - ROT up to 950°C**

- Formalized by Board as new product in 2006
- Builds on DPP reactor design
- First plants targeted for operation from 2016 time frame
- Collaborating with:
 - **Oil Sands Producers (SAGD Steam)**
 - Completed Pre-Feasibility Study
 - Feasibility Study Plan under development
 - **Petrochemical Industry (Process Steam)**
 - Pre-Feasibility Study underway
 - **SMR Hydrogen Producer (Power, Steam, Hydrogen)**
 - **US DOE (Power, Hydrogen, Process Heat)**
 - Completed NGNP Pre-conceptual Design
 - Conceptual Design /Plan under development

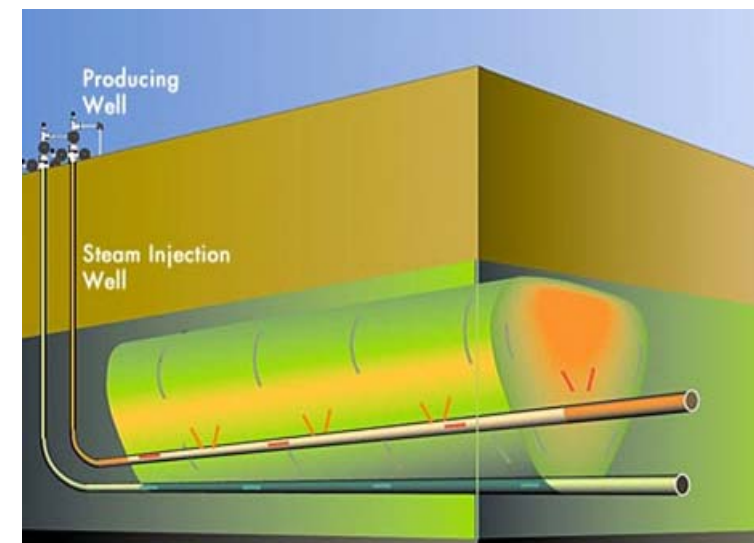
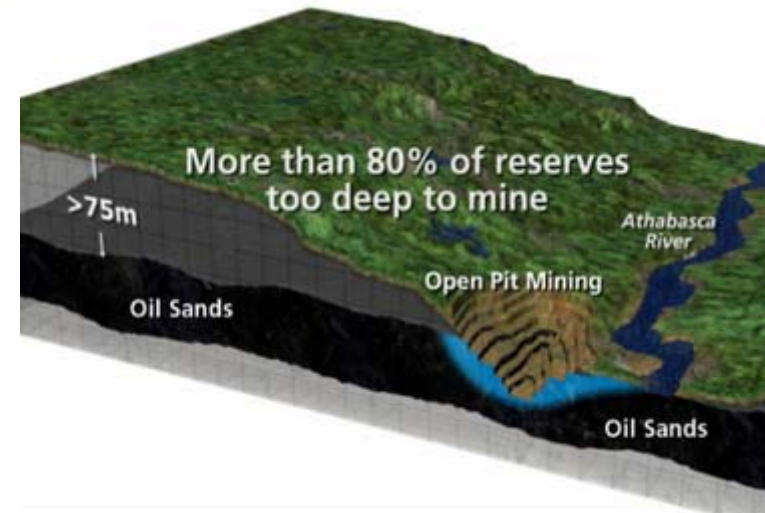


Oil Sands SAGD Concept

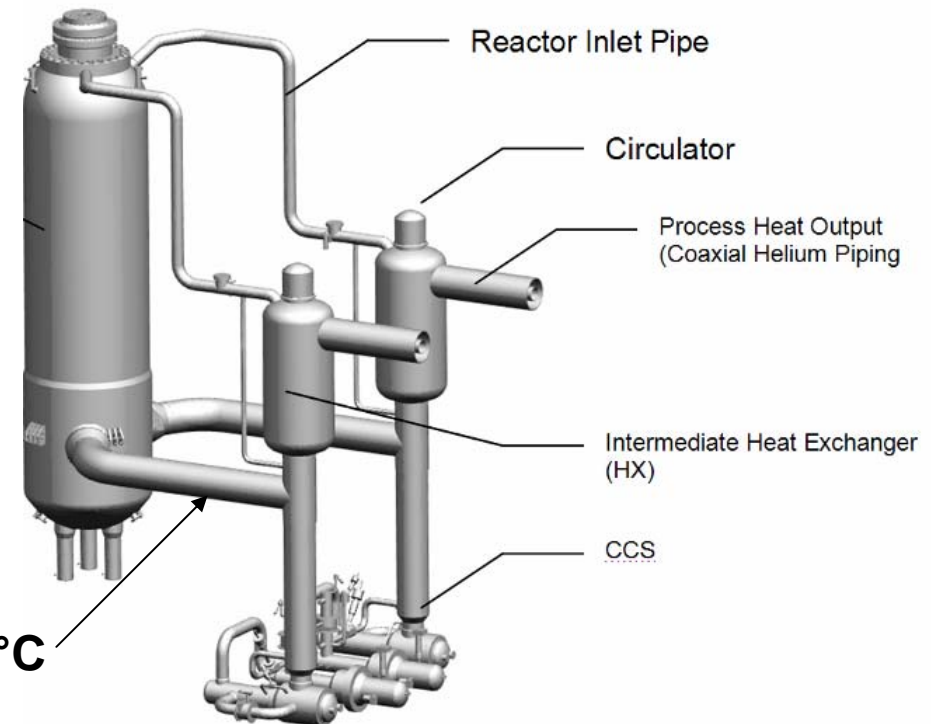
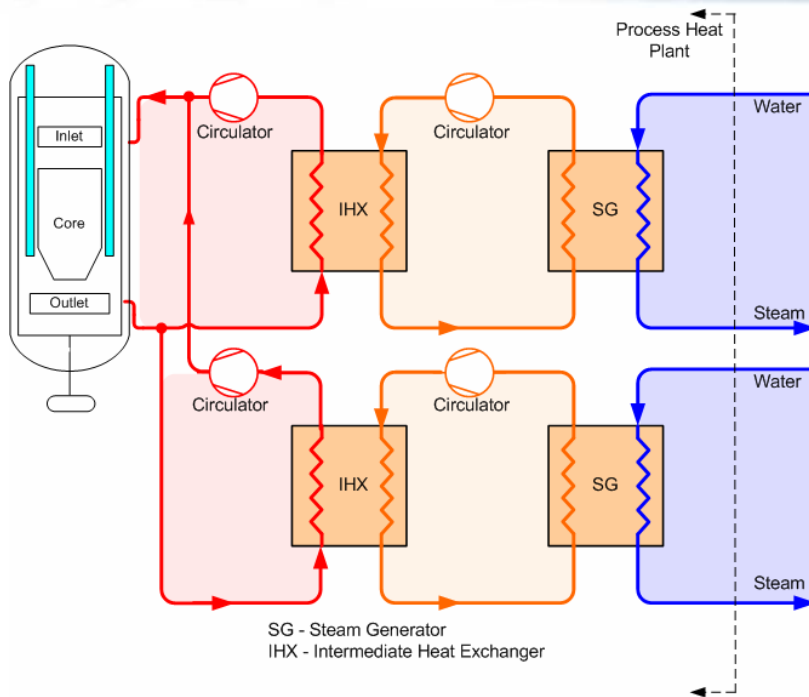


- **Steam production at well sites**
 - 500 MWt matches 50,000 bbl/day
 - Each reactor provides workable production increment
 - Cogeneration designs can provide stand-alone energy
 - Future options for hydrogen supply

- **High pressure steam supported by intermediate temperature design approach**
 - Minimum technology development
 - High reliability and maintainability
 - Production modularity and flexibility
 - Minimum nuclear footprint



Oil Sands SAGD Concept



**Reactor Output
Temperature (ROT) 750°C**



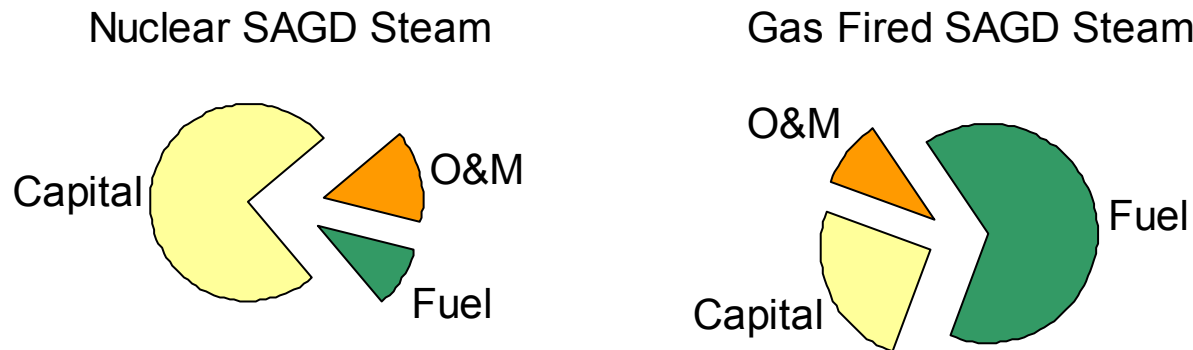
Oil Sands Market Economics



- **Value of 1-reactor Nuclear Cogen Plant based on:**
 - Displaces \$1-2B of natural gas plus capital and operating costs of current gas fired boilers and cogen units
 - Displaces CO₂ emissions from gas fired facilities and from potential use of bitumen, petcoke or other opportunity fuels
- **Competition**
 - Projected natural gas pricing and availability
 - Must demonstrate that nuclear option is more economical and less risky than bitumen/petcoke firing or gasification with CO₂ capture and sequestration (Oil Sands Industry studies underway)
- **Enables bitumen extraction expansion when otherwise constrained by limited gas supply and CO₂ compliance options**
 - Strategic industry option
 - Public and government policy support necessary



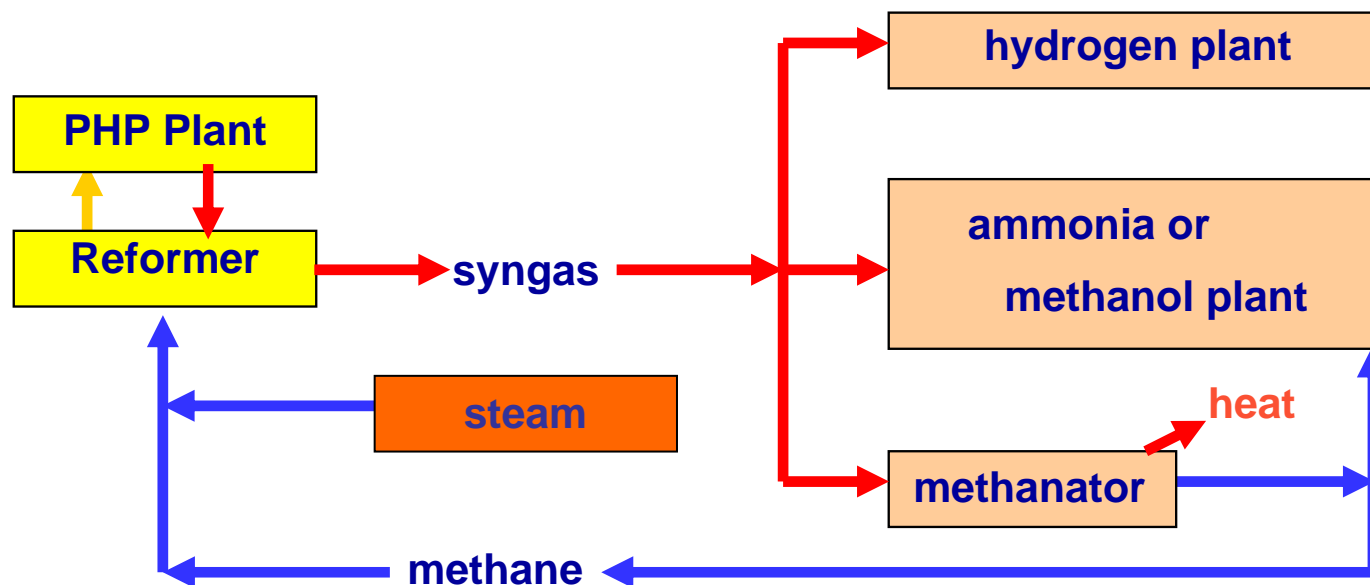
- **Cost of Nuclear Steam Production and Cogeneration**
 - Capital intensive option (vs existing fuel-intensive operations)



- Current construction in Alberta challenged by high field costs and cost growth
- Nuclear steam/cogen plant redesigned for modular construction and minimum field costs
- Low cost of capital important (some government participation in financing based on economic and environmental regional benefits)



- **Reformer Reaction**
 - $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$ (>800°C heat required)
- **PHP provides heat for reformer; displaces ~ 30% natural gas - eliminates flue gas CO₂ – most expensive to capture**
- **Remaining heat is used for steam or power co production**
- **Value of syngas expected to exceed projected plant costs**



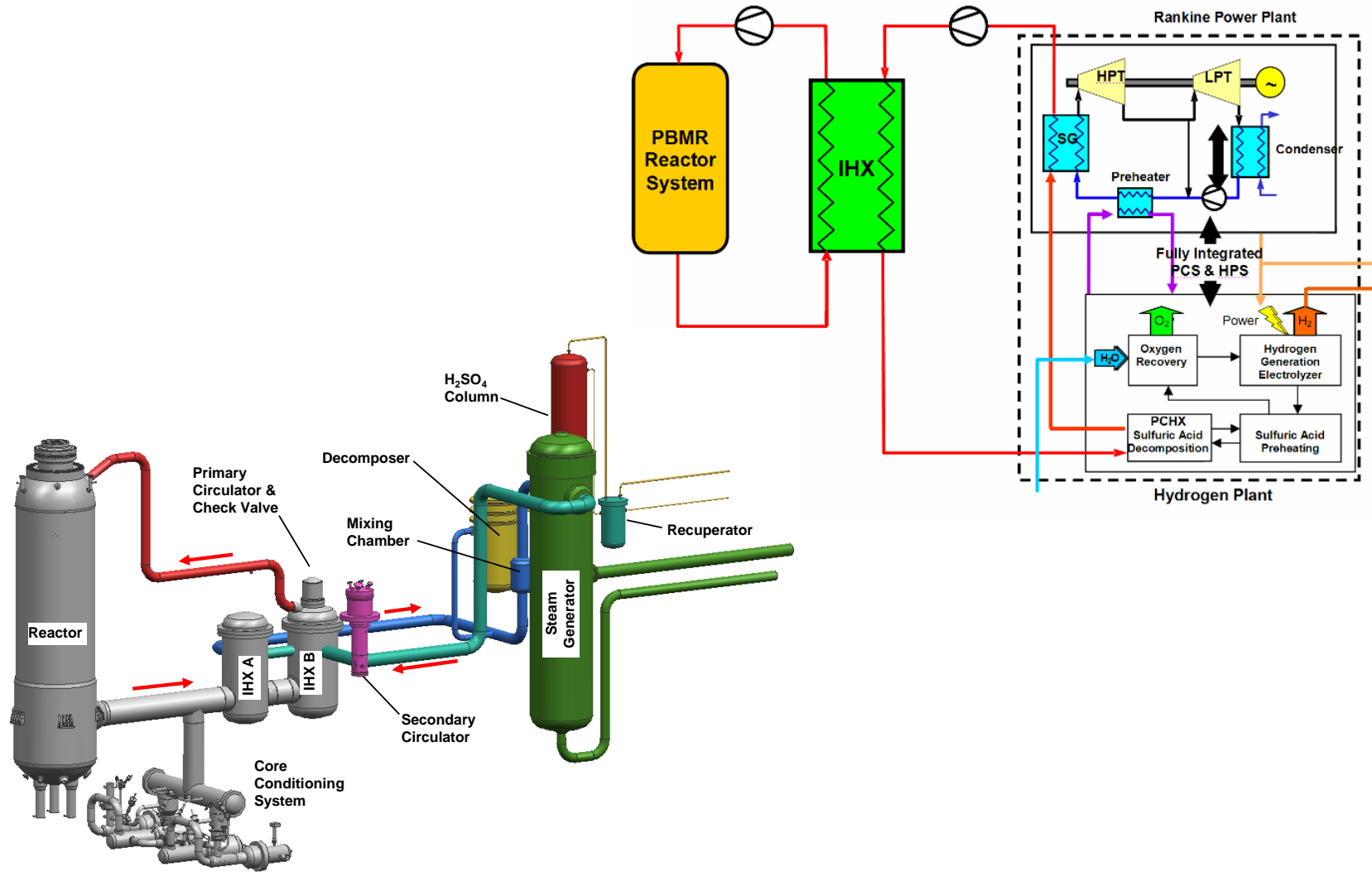


Nuclear Water-Splitting Concept



- **Several proposed Water-Splitting (WS) technologies including**
 - Conventional Water Electrolysis
 - High-Temperature Steam Electrolysis
 - Hybrid Sulfur Process
 - Sulfur Iodine Process
- **PBMR is looking for the most promising WS technology**
- **At present, PBMR selected the Hybrid Sulfur Process as reference cycle:**
 - $\text{H}_2\text{SO}_4 \rightarrow \text{SO}_2 + \text{H}_2\text{O} + \frac{1}{2} \text{O}_2$ (>800°C heat required)
 - $2\text{H}_2\text{O} + \text{SO}_2 \rightarrow \text{H}_2 + \text{H}_2\text{SO}_4$ (electrolytic at 100°C)
- **However, technology development is required to commercialize Hybrid Sulfur (HyS) WS**

Nuclear Water-Splitting Concept



Coal-to-Liquids Concept

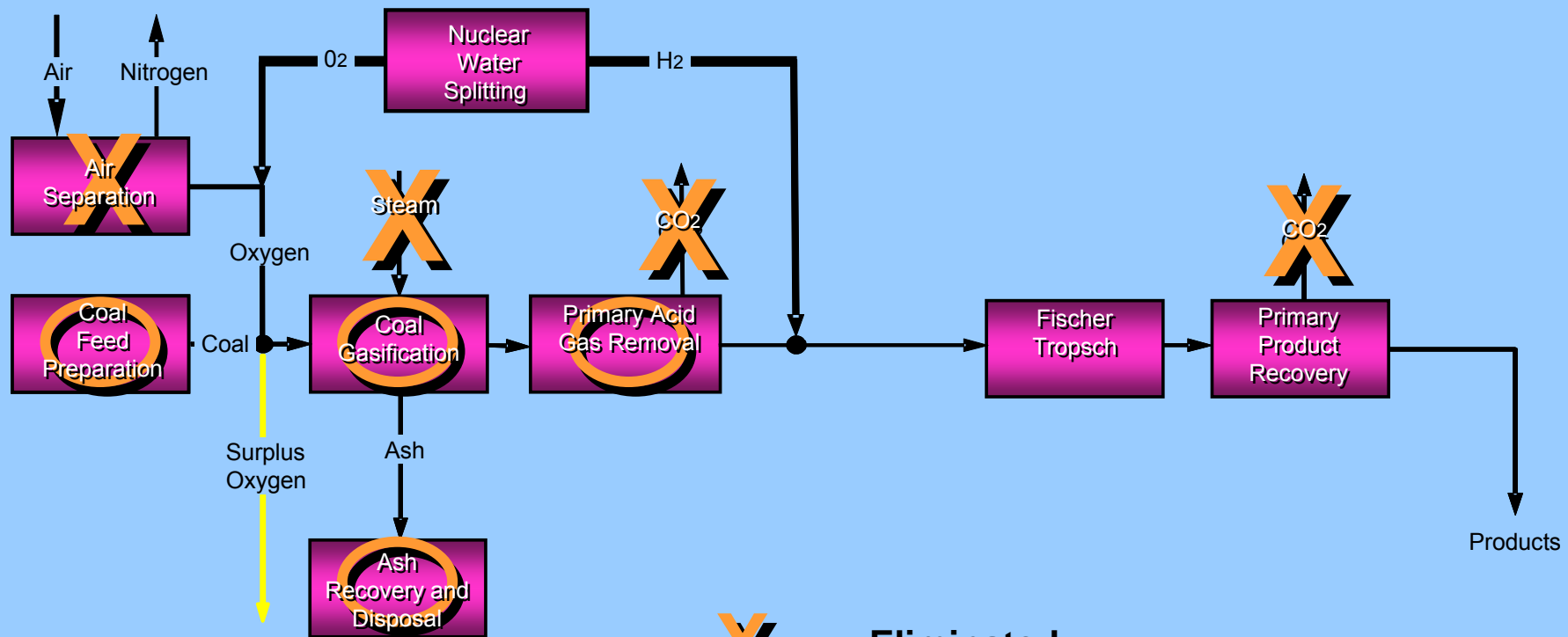


- **Initially developed in Germany in the 1920s**
- **Basis for coal-to-liquid fuel production by Sasol in the Republic of South Africa**
 - Provides ~30% of RSA gasoline and diesel fuel
 - Shaw/Badger is Sasol Technology partner
- **New CTL projects proposed**
- **CTL process is a significant user of hydrogen (coal gasification)**

Sasol South Africa, CTL Plant



Nuclear Water Splitting Simplifies Coal to Liquids



- Eliminated
- Reduced significantly
- Additional Gas Output



Market and Economics for Nuclear Water Splitting



● Value of Nuclear Water Splitting for CTL

- Displace gasification capacity, oxygen plant and related facilities dedicated to producing needed hydrogen (roughly half of syngas)
- Eliminate CO₂ production associated with converting half of coal to CO₂ just to make hydrogen
- Reduce coal consumption roughly in half

● Cost of Nuclear Water Splitting

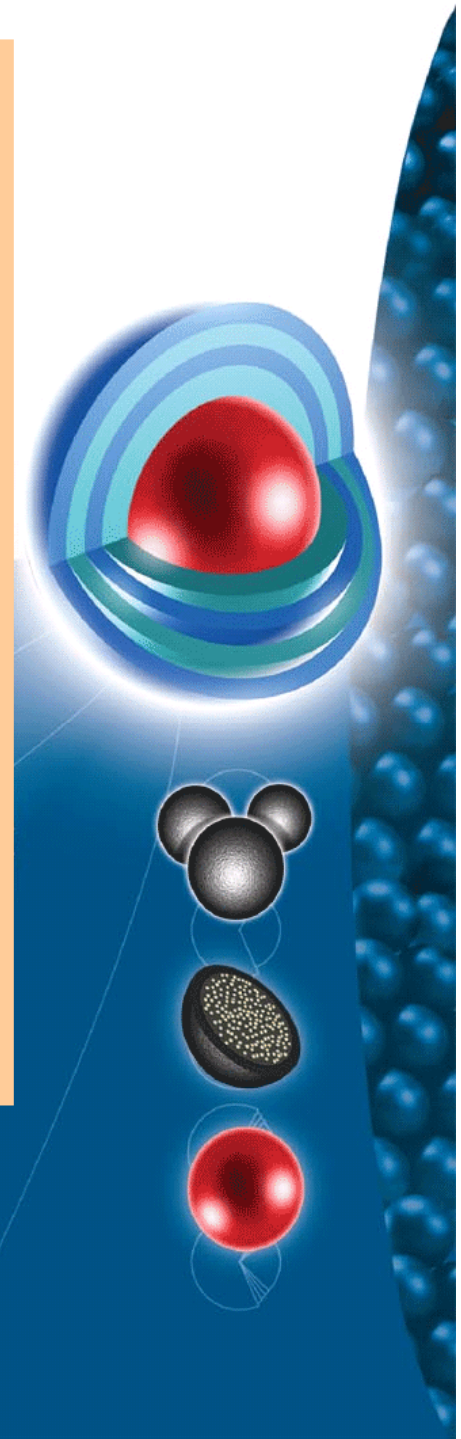
- Water splitting consumes large amounts of energy; many reactors needed for each gasifier train (producing H₂ from hydrocarbons is easier than splitting water)
- Replaces CO₂ intensive operation with capital intensive operation
- Requires development of efficient, low cost water splitting process
- Competition hinges on fossil fuel prices and CO₂ costs/credits



Summary



- **Generation IV HTR and ITR applications offer new non-power markets with near term entry opportunities**
- **PBMR initiatives are opening near term oil sands bitumen production market and other steam and cogen applications**
- **New technology development for nuclear steam methane reforming and water splitting promise mid and long-term opportunities for hydrogen production**
- **Innovation in plant design, modular construction, simplification of nuclear licensing, and development of public support and government policy are key factors in successful market entry**
- **Increasing support for nuclear energy as a strategic option to stabilize energy costs and offset CO₂ emissions promises improved market conditions**



Thank You